A Repository For Beyond-the-Standard-Model Tools

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Abstract

To aid phenomenological studies of Beyond-the-Standard-Model (BSM) physics scenarios, a web repository for BSM calculational tools has been created. We here present brief overviews of the relevant codes, ordered by topic as well as by alphabet. The online version of the repository may be found at:

`http://www.ippp.dur.ac.uk/montecarlo/BSM/`

1. Introduction

The physics programme at present and future colliders is aimed at a truly comprehensive exploration of the TeV scale. On the theoretical side, recent years have seen the emergence of an impressive variety of proposals for what physics may be uncovered by these machines in just a few years. The ideas range from hypotheses of new fundamental matter (e.g. right-handed neutrinos) or forces (Z' models), to new space-time symmetries (supersymmetry), or even new spatial dimensions — at times with singularly spectacular conseuqences, such as the possible production of microscopic black holes.

In the wake of many of these proposals, developments of computerised calculations of mass spectra, couplings, and experimental observables, have taken place. For others, such tools are yet to be created. Let it be stressed that this is not a point of only theoretical or phenomenological interest. Experiments and analyses are not constructed purely with mechanical tools. Theoretical predictions, for expected signal strengths as well as background levels, constitute a crucial part of the optimisation of both detectors, triggers, and analysis strategies. It is therefore essential to have access to tools for calculating observables for as wide a range of phenomenological signatures as possible.

The present brief overview and associated web repository aims to assess the present situation and facilitate the information gathering process for people wishing to perform phenomenological calculations in scenarios of physics beyond the Standard Model. We hope this may serve also to stimulate further work in the field. In Section 2., we first present a brief index of codes organised by physics topic. Next, in Section 3., a full, alphabetical overview is given, describing the contents of the repository at the time of writing. Other recent overviews of BSM-related physics tools can be found in [1–4].

2. Tools by Physics Topic

This section is merely intended as an index, useful for finding out which tools exist for a given physics scenario. The main repository is then described in alphabetical order in the next section.

Supersymmetry

- CALCHEP: MSSM tree-level matrix element generator. Phase space integration and event generation. Extensions possible.
- COMPHEP: MSSM tree-level matrix element generator. Phase space integration and event generation. Extensions possible.
- CPSUPERH: Higgs phenomenology in the MSSM with explict CP Violation.
- FEYNHIGGS: MSSM Higgs sector including explicit CP-violation (masses, couplings, branching ratios, and cross sections).
- HERWIG: Event generator for the MSSM (with and without RPV). Interface to ISAJET.
- ILCSLEPTON: NLO cross-sections for slepton production in e^+e^- and e^-e^- collisions.
- HDECAY: MSSM Higgs decay widths including loop effects.
- ISAJET: MSSM event generator. MSSM mass and coupling spectrum, decay widths. Checks against experimental constraints.
- MICROMEGAS: MSSM (work on CPV in progress) and NMSSM dark matter relic density.
- NMHDECAY: NMSSM mass spectrum plus couplings and decay widths of all Higgs bosons. Checks against experimental constraints.
- O'MEGA: MSSM tree-level matrix element generator. Extensions possible.
- PROSPINO: SUSY-NLO cross sections at hadron colliders.
- PYTHIA: MSSM event generator. RPV decays. Extensions to R-hadrons and NMSSM available.
- SDECAY: MSSM decay widths including loop effects.
- SHERPA: MSSM event generator.
- SOFTSUSY: MSSM mass and coupling spectrum.
- SPHENO: MSSM mass and coupling spectrum, decay widths, and e^+e^- cross sections.
- SUSPECT: MSSM mass and coupling spectrum.
- SUSY-MADGRAPH: MSSM Matrix Elements.
- SUSYGEN3: MSSM event generator (with and without RPV).

Extra Dimensions

- CHARYBDIS: Black hole production in hadron-hadron collisions.
- HERWIG: Resonant graviton production in hadron-hadron collisions.
- MICROMEGAS: Dark matter relic density. UED and warped extra dimensions being implemented.
- PANDORA/PANDORA-PYTHIA: ADD extra dimensions. Work in progress: UED.
- PYTHIA: RS graviton excitations.
- PYTHIA_UED: Universal Extra Dimensions.
- SHERPA: ADD extra dimensions.
- TRUENOIR: Black hole production.

Extra Gauge Bosons, Z'/W' models.

- PANDORA/PANDORA-PYTHIA: Z' models.
- PYTHIA: Z' and W' models.

Other Exotics

- O'MEGA: Anomalous triple and quartic gauge couplings. Extensions possible.
- GR@PPA.LEPTOQUARK: Leptoquark event generator for pp and $\mathrm{p\bar{p}}$ collisions.
- PYTHIA: Technicolor, doubly charged Higgs bosons, excited fermions, anomalous couplings, leptoquarks, fourth generation fermions.

3. Tools by Alphabet

We here give a detailed alphabetical list of the tools present in the repository at the time these proceedings went to press. Note that the preceding section contains a useful list of tools by topic, i.e. which tools are relevant for extra dimensions, which ones for Z' etc.

CalcHEP

Responsible Person: A. Pukhov, `pukhov@lapp.in2p3.fr`

Web Page: `http://theory.sinp.msu.ru/~pukhov/calchep.html`

CALCHEP is a program for symbolic calculation of matrix elements and generation of C-codes for subsequent numerical calculations. The model has to be defined in tems of lists of variables, constraints, particles and list of vertices. Various BSM can be implemented and investigated. In partiqular CALCHEP links to SUSPECT, ISAJET, SOFTSUSY, and SPHENO for MSSM. It also contains a Monte Carlo generator for unweighted events and a simple program which passes these events to PYTHIA. CALCHEP is a menu driven system with context help facility and is accompanied by a manual. At the same time CALCHEP can be used in the non-interactive regime as a generator of matrix elements for other programs. In this mode it is implemented in MICROMEGAS for automatic generation of matrix elements of annihilation and co-annihilation of super-particles. Restrictions: tree level matrix elements, not more than 6 particles in initial/final states. The last restriction is caused by modern computer facilities and by the implemented method of calculation (squared amplitudes). But for calculation of separate diagrams it was successfuly used for 2→5 and 2→6 processes.

Charybdis

Responsible Person: P. Richardson, `Peter.Richardson@durham.ac.uk`

Web Page: `www.ippp.dur.ac.uk/montecarlo/leshouches/generators/charybdis/`

Charybdis simulates black hole production in hadron-hadron collisions using a geometric approximation for the cross section together with Hawking evaporation of the black hole using the correct grey-body factors. It is described in more detail in [5].

CompHEP

Responsible Person: Sasha Sherstnev, `sherstnv@theory.sinp.msu.ru`

Web Page: `http://theory.sinp.msu.ru/comphep`

The COMPHEP package was created for calculation of multiparticle final states in collision and decay processes. The main idea in COMPHEP was to enable one to go directly from the lagrangian to the cross sections and distributions effectively, with the high level of automation. The officially supported models are SM (in two gauges), unconstrained MSSM (in two gauges), MSSM with SUGRA and Gauge-Mediated SUSY breacking machanisms. The special program LANHEP allows new BSM models to be implemented to COMPHEP.

CPsuperH

Responsible Persons: J. S. Lee, `jslee@hep.man.ac.uk`
A. Pilaftsis, `pilaftsi@mail.cern.ch`
Web Page: `http://www.hep.man.ac.uk/u/jslee/CPsuperH.html`

CPsuperH [6] is a newly-developed computational package that calculates the mass spectrum, couplings and branching ratios of the neutral and charged Higgs bosons in the Minimal Supersymmetric Standard Model with explicit CP violation. The program is based on recent renormalization-group-improved diagrammatic calculations that include dominant higher-order logarithmic and threshold corrections, b-quark Yukawa-coupling resummation effects and Higgs-boson pole-mass shifts.

The code CPsuperH is self-contained (with all subroutines included), is easy and fast to run, and is organized to allow further theoretical developments to be easily implemented. The fact that the masses and couplings of the charged and neutral Higgs bosons are computed at a similar high-precision level makes it an attractive tool for Tevatron, LHC and LC studies, also in the CP-conserving case.

FeynHiggs

Responsible Person: T. Hahn, `hahn@mppmu.mpg.de`
S. Heinemeyer, `Sven.Heinemeyer@cern.ch`
Web Page: `http://www.feynhiggs.de`

FeynHiggs is a program for computing MSSM Higgs-boson masses and related observables, such as mixing angles, branching ratios, couplings and production cross sections, including state-of-the-art higher-order contributions (also for the case of explicit CP-violation). The centerpiece is a Fortran library for use with Fortran and C/C++. Alternatively, FeynHiggs has a command-line, Mathematica, and Web interface. The command-line interface can process, besides its native format, files in SUSY Les Houches Accord format. FeynHiggs is an open-source program and easy to install. A web-based interface is available at `www.feynhiggs.de/fhucc`. For further information, see also [7–11].

GR@PPA.Leptoquark

Responsible Person: S. Tsuno, `Soushi.Tsuno@cern.ch`
Web Page: `http://atlas.kek.jp/physics/nlo-wg/index.html`

GR@PPA event generator for Leptoquark model. The code generates unweighted events for scalar or vector type Leptoquark models. The Leptoquarks are generated, and decayed into quark and lepton(neutrino) so that the decay properties of the final particles are correctly handled. In the vector Leptoquark production, two anomalous couplings are included in the interaction vertices. The decay mode depends on the model induced in the unified theory. The program thus keeps flexibility for the Leptoquark decay. The details description can be found on the web page, where also the model file which contains the Leptoquark interaction for the GRACE system is available.

HDecay

Responsible Person: M. Spira, `Michael.Spira@psi.ch`
Web Page: `http://people.web.psi.ch/spira/hdecay/`

HDECAY [12] calculates the branching ratios and total widths of SM and MSSM Higgs bosons.

Herwig

Responsible Person: P. Richardson, `Peter.Richardson@durham.ac.uk`

Web Page: `http://hepwww.rl.ac.uk/theory/seymour/herwig/`

HERWIG [13] is a general purpose event generator for the simulation of Hadron Emission Reactions With Interfering Gluons. The main concentration is on the simulation of the Standard Model although SUSY (with and without RPV [14]) is implemented together with resonant gravition production in hadron-hadron collisions.

ILCslepton

Responsible Person: A. Freitas, `afreitas@physik.unizh.ch`

Web Page: `http://theory.fnal.gov/people/freitas/`

The programs calculate the complete electroweak one-loop corrections to slepton production in $\mathrm{e^+e^-}$ and $\mathrm{e^-e^-}$ collisions (i.e. at ILC). Besides the virtual loop corrections, real photon radiation is included in order to provide a finite and well-defined result. For the sake of consistent renormalization, the programs take the MSSM soft breaking parameters at an arbitrary scale as input; it is not possible to use masses and mixing angles as input parameters. The available codes allow the computation of the total and angular differential cross-sections for selectron, smuon and sneutrino production. For more information, see [15, 16].

Isajet

Responsible Person: H. Baer, `baer@hep.fsu.edu`

Web Page: `http://www.phy.bnl.gov/~isajet/`

Simulates pp, $\mathrm{\bar{p}p}$, and $\mathrm{e^+e^-}$ interactions at high energies. Calculates SUSY and Higgs spectrum along with SUSY and Higgs 2 and 3 body decay branching fractions. Evaluates neutralino relic density, neutralino-nucleon scattering cross sections, $\mathrm{Br(b \to s\gamma)}$, $(g-2)_\mu$, $\mathrm{Br(B_s} - > \mu^+\mu^-)$.

micrOMEGAs

Responsible Person: G. Bélanger, `belanger@lapp.in2p3.fr`

Web Page: `http://lappweb.in2p3.fr/lapth/micromegas/index.html`

MICROMEGAS is a code that calculates the relic density of the dark matter in supersymmetry. All annihilation and coannihilation processes are included. The cross-sections, extracted from CALCHEP, are calculated exactly using loop-corrected masses and mixings as specified in the SUSY Les Houches Accord. Relativistic formulae for the thermal average are used and care is taken to handle poles and thresholds by adopting specific integration routines. In the MSSM, the input parameters can be either the soft SUSY parameters or the parameters of a SUGRA model specified at the GUT scale. In the latter case, a link with SUSPECT, SOFTSUSY, SPHENO and ISAJET allows to calculate the supersymmetric spectrum, Higgs masses, as well as mixing matrices. Higher-order corrections to Higgs couplings to quark pairs including QCD as well as some SUSY corrections are implemented. Cross-sections for any 2→2 process as well as partial decay widths for two-body final states are provided. Cross-sections for neutralino annihilation at v∼0, relevant for indirect detection of neutralinos, are automatically computed. In the MSSM, routines calculating $(g-2)_\mu$, $\mathrm{Br(b \to s\gamma)}$, $\mathrm{Br(B_s \to \mu^+\mu^-)}$ are also included.

MICROMEGAS can be extended to other models by specifying the corresponding model file in the CALCHEP notation.

NMHDecay

Responsible Person: U. Ellwanger, `ellwanger@th.u-psud.fr`

Web Page: `http://www.th.u-psud.fr/NMHDECAY/nmhdecay.html`

The Fortran code NMHDECAY computes the sparticle masses and masses, couplings and decay widths of all Higgs bosons of the NMSSM in terms of its parameters at the electroweak (SUSY breaking) scale: the Yukawa couplings λ and κ, the soft trilinear terms A_λ and A_κ, and $\tan(\beta)$ and $\mu_{\rm eff} = \lambda < S >$. The computation of the Higgs spectrum includes the leading two loop terms, electroweak corrections and propagator corrections. Each point in parameter space is checked against negative Higgs bosons searches at LEP, including unconventional channels relevant for the NMSSM. A link to a NMSSM version of MICROMEGAS allows to compute the dark matter relic density, and a rough (lowest order) calculation of the BR($\mathrm{s} \to \mathrm{b}\gamma$) is perfromed. One version of the program uses generalized SLHA conventions for input and output. For further information, see also [17, 18].

O'Mega

Responsible Person: T. Ohl, `ohl@physik.uni-wuerzburg.de`

Web Page: `http://theorie.physik.uni-wuerzburg.de/~ohl/omega/`

O'Mega contructs optimally factorized tree-level scattering amplitudes (starting from 2→4 processes, the expressions are much more compact and numerically stable than naive sums of Feynman diagrams). Officially supported models are the Standard Model and the complete MSSM (since version 0.10, of November 2005). Users can add new interactions (e.g. anomalous triple and quartic gauge couplings are part of the distributed version).

Complete automatized event generation for the LHC and the ILC is possible in concert with WHiZard.

Pandora

Responsible Person: M. Peskin, `mpeskin@slac.stanford.edu`

Web Page: `http://www-sldnt.slac.stanford.edu/nld/new/Docs/Generators/PANDORA.htm`

Pandora is a parton-level physics simulation for $\mathrm{e}^+\mathrm{e}^-$ linear colliders, including polarization and beam effects. Pandora comes with an interface, Pandora-Pythia, that hadronizes events with Pythia and decays polarized taus with tauola. The current distribution (Pandora 2.3) includes an implementation of the ADD extra dimension model ($\mathrm{e}^+\mathrm{e}^- \to \gamma\mathrm{G}$ and virtual graviton exchange in $\mathrm{e}^+\mathrm{e}^- \to \mathrm{f}\bar{\mathrm{f}}$, $\mathrm{W}^+\mathrm{W}^-$, ZZ, $\gamma\gamma$), and a two-parameter Z' model. We are currently working on inclusion of more general Z' models and inclusion of UED production and decay.

Prospino

Responsible Person: T. Plehn, `tilman.plehn@cern.ch`

Web Page: `http://pheno.physics.wisc.edu/~plehn`

For most applications the uncertainty in the normalization of Monte Carlos for the production of two supersymmetric particles is large. The reason are large SUSY and SUSY-QCD corrections to the cross section. Prospino2 is the tool you can to use to normalize your total rates. Some distributions are available on request. For detailed information on the production processes included, on papers available for more information, and on downloading and running the code, please see the web pages.

Pythia

Responsible Person: P. Skands, `skands@fnal.gov`

Web Page: `http://www.thep.lu.se/∼torbjorn/Pythia.html`

In the context of tools for extra dimensions, PYTHIA contains cross sections for the production of Randall-Sundrum graviton excitations, with the parton showers corrected to RS+jet matrix elements for hard jet radiation [19]. PYTHIA can also be used for a number of other BSM physics scenarios, such as Technicolor [20], Z'/W' [21] (including interference with Z/γ and W bosons), Left–Right symmetry (Higgs triplets), leptoquarks, compositeness and anomalous couplings (including excited quarks and leptons), and of course a large variety of SUSY signals and scenarios (for R-hadrons see [22]; for RPV see [23, 24]; for the NMSSM see [25]). Interfaces to SLHA, ISAJET, and FEYNHIGGS are available. For further information, see the PYTHIA manual [26], Chapter 8, and the PYTHIA update notes, both available on the PYTHIA web page.

Pythia_UED

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M. El Kacimi
D. Goujdami

Web Page: `http://wwwlapp.in2p3.fr/∼przys/PythiaUED.html`

A generator tool which uses PYTHIA to produce events in the UED (Universal Extra Dimensions) model of Appelquist, Cheng and Dobrescu [27], with one extra dimension and additional gravity mediated decays [28].

SDecay

Responsible Person: M. Mühlleitner, `muehl@lapp.in2p3.fr`

Web Page: `http://lappweb.in2p3.fr/pg-nomin/muehlleitner/SDECAY/`

Calculates the 2- and 3-body decays and loop-induced decays of the supersymmetric particles including the QCD corrections to the decays involving coloured particles and the dominant electroweak effects to all decay modes.

Sherpa

Responsible Person: S. Schumann, F. Krauss, `sherpa@theory.phy.tu-dresden.de`

Web Page: `http://www.sherpa-mc.de/`

SHERPA [29] is a multi-purpose Monte Carlo event generator that is able to simulate high-energetic collisions at lepton and hadron colliders. The physics programme of SHERPA covers: 1) The description of hard processes in the framework of the Standard Model, the Minimal Supersymmetric Standard Model and the ADD model of large extra dimensions using tree level matrix elements provided by its internal matrix element generator AMEGIC++ [30, 31]. 2) Multiple QCD bremsstrahlung from initial and final state partons. 3) The consistent merging of matrix elements and parton showers according to the CKKW prescription. 4) Jet fragmentation and hadronisation provided by an interface to PYTHIA. 5) The inclusion of hard underlying events.

Softsusy

Responsible Person: B. C. Allanach, `B.C.Allanach@damtp.cam.ac.uk`

Web Page: `http://allanach.home.cern.ch/allanach/softsusy.html`

This code provides a SUSY spectrum in the MSSM consistent with input low energy data, and a user supplied high energy constraint (eg minmal SUGRA). It is written in C++ with an emphasis on easy generalisability. Full three-family couplings and renormalisation group equations are employed, as well as one-loop finite corrections a la Bagger, Matchev, Pierce and Zhang. It can produce SUSY Les Houches Accord compliant output, and therefore link to Monte-Carlos (eg PYTHIA) or programs that calculate decays, (e.g. SDECAY). If you use SOFTSUSY to write a paper, please cite [32], which is the SOFTSUSY manual. The version on the electronic hep-ph/ archive will be updated with more recent versions. To run SOFTSUSY, you should only need standard C++ libraries. CERNLIB and NAGLIB are not required. The code has been successfully compiled so far using `g++` on SUN, DEC ALPHA and PC systems (linux, sun UNIX and OSF). It is supposed to be standard ANSI compatible C++ (and does not contain any templates).

SPheno

Responsible Person: W. Porod, `porod@ific.uv.es`

Web Page: `http://www-theorie.physik.unizh.ch/~porod/SPheno.html`

Solves the SUSY RGEs at the 2-loop level for various high scale models. The obtained parameters are used to calculate the SUSY and Higgs spectrum using the complete 1-loop formulas and in case of the Higgs bosons in addition the 2-loop corrections due to Yukawa interactions. This spectrum is used to calculate SUSY and Higgs decay branching ratios and the production of these particles in e+ e- annihilation.

SuSpect

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Web Page: `http://www.ippp.dur.ac.uk/montecarlo/BSM/www.lpta.univ-montp2.fr/users/kneur/Suspect/`

Calculates the SUSY and Higgs particle spectrum in the general MSSM or more contrained scenarios.

SUSY-MadGraph

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D. Rainwater, `rain@pas.rochester.edu`

Web Page: `http://www.pas.rochester.edu/~rain/smadgraph/smadgraph.html`
`http://pheno.physics.wisc.edu/~plehn/smadgraph/smadgraph.html`

SUSY-MADGRAPH [30] generates Fortran code for MSSM matrix elements, which use the HELAS library. MSSM here means R-parity conserving, no additional CP violation, and two Higgs doublets. A corresponding event generator based on MADEVENT is under construction.

Susygen3

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Web Page: http://lyoinfo.in2p3.fr/susygen/susygen3.html

SUSYGEN 3.0 [33] is a Monte Carlo program designed for computing distributions and generating events for MSSM sparticle production in $\mathrm{e^+e^-}$, $\mathrm{e^\pm p}$ and pp ($\mathrm{p\bar{p}}$) collisions. The Supersymmetric (SUSY) mass spectrum may either be supplied by the user, or can alternatively be calculated in different models of SUSY breaking: gravity mediated supersymmetry breaking (SUGRA), and gauge mediated supersymmetry breaking (GMSB). The program incorporates the most important production processes and decay modes, including the full set of R-parity violating decays, and the decays to the gravitino in GMSB models. Single sparticle production via a R-parity violating coupling is also implemented. The hadronisation of the final state is performed via an interface to PYTHIA.

TrueNoir

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Web Page: http://hep.brown.edu/users/Greg/TrueNoir/index.htm

A Monte Carlo package, TRUENOIR, has been developed for simulating production and decay of the black holes at high-energy colliders. This package is a plug-in module for the PYTHIA [34] Monte Carlo generator. It uses a euristic algorithm and conservation of barion and lepton numbers, as well as the QCD color, to simulate the decay of a black hole in a rapid-decay approximation. While the limitations of this approach are clear, further improvements to this generator are being worked on. In the meantime, it provides a useful qualitative tool to study the detector effects and other aspects of the BH event reconstruction. At the present moment, the generator works for $\mathrm{e^+e^-}$ and $\mathrm{p\bar{p}}$ collisions. The proton-proton collisions are being added; their characteristic is not expected to differ much from those in $\mathrm{p\bar{p}}$ interactions, so the user is advised to use the $\mathrm{p\bar{p}}$ mode to generate events at the LHC or VLHC until further notice.

4. Outlook

We present an overview of the tools available in a newly created web repository for Beyond-the-Standard Model physics tools, at the address:
http://www.ippp.dur.ac.uk/montecarlo/BSM/

Most of these tools focus on supersymmetry, but there is a growing number of tools for more ‘exotic’ physics becoming available as well. With a series of at least 3 workshops directly focussing on tools in 2006, and with the Les Houches activities picking up again in 2007, we anticipate that this list will be expanded considerably before the turn-on of the LHC in 2007. For the year 2006, the main tools-oriented workshops are:

1. MC4BSM, Fermilab, Mar 20-21, 2006.
   http://theory.fnal.gov/mc4bsm/
2. Tools 2006, Annecy, Jun 26-28, 2006.
   http://lappweb.in2p3.fr/TOOLS2006/

3. MC4LHC, CERN, Jul 17 - 26, 2006.

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